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Thermal comfort analyses of elementary school students in the tropical region

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Abstract: This study aimed to analyse the thermal comfort level of students in primary school classrooms in the tropical region with the case studies done in Makassar, Indonesia. The data collection was done through a survey in the six selected primary schools in Makassar. The study involved 1,111 students from 33 classrooms. The recorded data includes personal data and the thermal environments, i.e. air temperature, air humidity, mean radiant temperature (MRT), and airflow velocity. At the same time, students were asked to fill out questionnaires asking their comfort level perceived at the time of measurements. The results showed that Temperatures range from 28.33°C in the morning (8:00 am) to 34.29°C in the afternoon (2:20 pm). Air humidity ranges from 53% to 89% with an average of 68%. Students experienced relatively stagnant airflow conditions characterised by a minimum 0m/s, an average 0.1m/s, and a maximum 1.45m/s of air velocity. The elementary school students are quite tolerant to high temperatures. Even though only a small percentage of respondents (28%) feel neutral in comparison with respondents who feel warm and hot (43%), 86% of them accepted these conditions. However, more than 72% of respondents preferred to decrease the air temperature in the classrooms.

Keywords: Air temperature; elementary schools; neutral temperature; thermal comfort.

1. Introduction

Thermal comfort is one of the requirements for workers that enable them to work well and more productively. Sensharma *et al.* (1998) found that there was a positive correlation between room environment and the productivities of workers in the office building. This thermal comfort is not just requirement for office buildings but also for educational buildings. A quite old study back in 1968 revealed that there was a positive effect on the thermal quality of classrooms on students' performances (Pepler and Warner, 1968). An extensive literature review by Mendell and Heath (2005) showed a good correlation between indoor school environments (which include thermal comfort) and the performance and attendance of children.

Thermal comfort standards such as ASHRAE Standard 55 (ASHRAE, 2004) has been widely used as a reference for designing thermal comfort in many countries, including Indonesia. To examine the performance of thermal comfort experienced by users, then according to this specification, a survey using a questionnaire should be carried out. This questionnaire asks the thermal sensation votes (TSV) of

respondents in seven scales, namely: hot (+3), warm (+2), slightly warm (+1), neutral (0), slightly cool (-1), cool (-2), and cold (-3). However, long before, Bedford (1936) has also proposed a method for evaluating thermal comfort which also consists of seven scales. They are: much too warm (+3), too warm (+2), comfortably warm (+1), comfortable (0), comfortably cool (-1), too cool (-2), and much too cool (-3). In this research, The Bedford scale was named thermal comfort vote (TCV). Besides measuring the thermal comfort using questionnaire method, the thermal comfort can also be estimated using the Predicted Mean Vote (PMV) developed by Fanger (1970). According to Fanger (1970), the PMV can be calculated by using two personal parameters (clothing and the activity of respondents), and for environmental parameters (air temperature, MRT, relative humidity, and air velocity).

Most schools in Indonesia were built as a prototype building, with no consideration based on the local climatic conditions. The schools have been constructed to the same standards regardless of the user's comfort, in this case, the students of the primary school, which are young (6-12 years). During daytime, the classrooms are excessively dependent on the natural ventilation system, which is not enough to make classrooms comfortable. The condition of the classrooms is still very far from comfortable conditions. The number of classrooms equipped with fans. Since the morning of the classroom has been assisted by the airflow from the fan to make the students comfortable in participating in learning in their classrooms. It is what lies behind the author to conduct this study in elementary schools in the city of Makassar. Specifically, the authors will discuss two issues in this article, as follows:

- Thermal environmental conditions of elementary school classrooms in Makassar.
- Users' responses (students) to the thermal environmental conditions of the classrooms.

2. Research Method

2.1. Data collection

This research is a preliminary study of thermal comfort analyses of naturally ventilated classroom carried out in six primary schools in Makassar. The study was conducted at the 33 classrooms, which is used for teaching and learning process. The buildings consisted of one and two-storey buildings. The buildings should provide comfortable indoor environments including thermal comfort for occupants.

The data collection has been carried out using several instruments. The LSI-Lastem Thermal Comfort Multi Logger (LSI TC) is a set of instrument, which consists of several sensors and data logger. The arrangements of LSI TC applied in this survey including one data logger and four sensors. The sensors including a globe thermometric probe (BST131) for measuring mean radiant temperature (MRT), a portable psychometric forced ventilation probe (BSU102) for measuring air temperature and relative humidity, and a wet bulb temperature probe (BSU121) for measuring wet bulb temperature. The instruments were placed in the classrooms. In addition to LSI TC, the measurement also recorded by six Hobo Loggers. Two types of loggers were used, i.e. the Hobo temp/RH logger and the HOBO temp/RH/Light/External. Four Hobo temp/RH loggers (Hobo-1) were used for measuring air temperature, and relative humidity, and two Hobo temp/RH/Light/External loggers (Hobo-2) were used for measuring air temperature, relative humidity, and air velocity.

The collection of data was carried out as follows:

- Survey on objective measurement was conducted to collect the personal and the thermal environment data. Personal data was gathered by collecting the clothing and the activity of each

respondent. The thermal environmental variables, i.e. air temperature, mean radiant temperature (MRT), relative humidity, and air velocity were recorded by using instruments as mentioned before. The instruments and their position in the measured classrooms are shown in Figure 1. The sensors were attached at 100 cm above the floor level (Wong and Khoo, 2003). Because of the limitation of equipment, the MRT only recorded at one point that was at point A, while the air velocity recorded at two points (A and B).

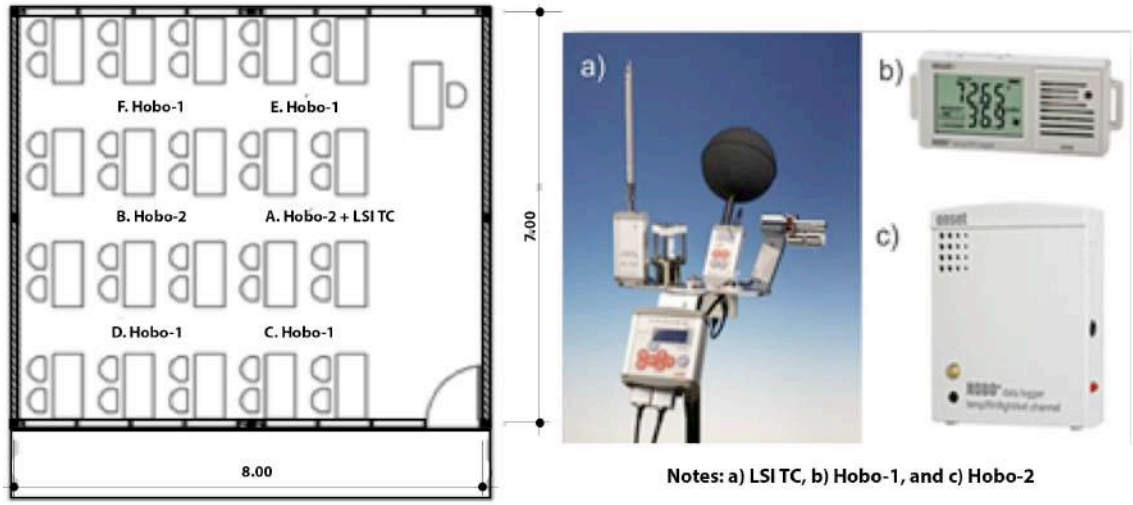

Figure 1: The arrangement of instruments in the typical classroom

- Survey on subjective measurement, which was conducted to measure the level of thermal comfort of respondents. The study carried out by using questionnaire technique, which was adapted from Wong and Khoo (2003).The modified questionnaire has been used for research in the naturally ventilated classrooms in Makassar (Hamzah *et al.*, 2016). For this study, the questionnaire has been adapted to accommodate seven questions, four questions related to the thermal aspect which captured the thermal sensation vote (TSV), thermal comfort vote (TCV), thermal preference and thermal acceptance of respondents. Two questions related to the air velocity votes and the air velocity preference. Lastly, one question related to the respondents votes on the humidity of classrooms.

2.2. Data processing and analyses

Data analyses were carried out by spreadsheet software MS Excel. The spreadsheet has been used to calculate the mean value of environmental variables and to generate tables showing the percentage of TSV, TCV, and PMV. For the statistical analyses, a statistical software SPSS version 16 has been used to show graphical of respondents' votes and the calculation of regression analyses. To calculate the PMV for each defendant, the availability of four corresponding environmental variables as well as two personal variables for each respondent is essential. The calculation was done using spreadsheet template developed by Tanabe (Farina, 2015).

Research results were analysed based on the statistical analyses using SPSS version 16. The statistical analysis employed in this study were graphical and regression analysis. The regression analyses were determined by two criteria, i.e. test of linearity of regression and the significance of equation coefficient. Before analysing the data using statistical analysis, the data have been verified. One method of verification is to check their normality and reliability. The checking required making sure that the results are valid for concluding. All data have been checked for their normality and reliability.

3. Results and Discussion

3.1 Research Sample

Surveys and measurements of thermal comfort and thermal environments have been carried out in six primary schools in the city of Makassar, which represent the six sub-districts. The locations of schools are spread out from the city centre to the suburbs (Figure 2).

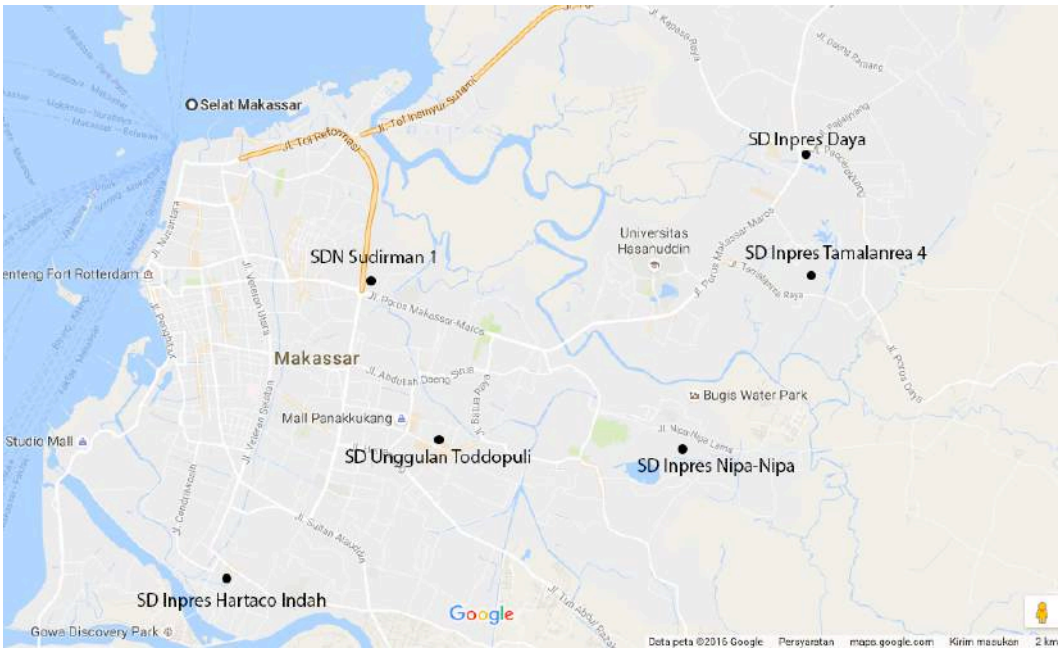

Figure 2 Location of surveyed elementary schools in Makassar

The following part explains the particular area of each school. SD Inpres Nipa-nipa located in a suburban area with a location farther away from the concentration of settlements. SDN Sudirman 1 located in the city centre near to the town square, along with three other primary schools in the same location. SD Inpres Tamalanrea 4 established in a dense residential area bordering the road environment. SD Inpres Daya positioned near the local commercial area, 13 Km away from the city centre, and it is adjacent to arterial roads. SD Inpres Hartaco Indah located in residential areas with medium density. SD Unggulan Toddopuli found in the medium density residential and commercial areas. Table 1 lists the characterisations of the samples.

Table 1: Characteristic of samples

No.	Name of school	Location (sub-district)	Number of classes	Number of students	Date of survey/ measurement
1	SD Inpres Nipa-nipa	Manggala	5	157	21 April 2016
2	SDN Sudirman 1	Ujung Pandang	6	205	29 April 2016
3	SD Inpres Tamalanrea 4	Tamalanrea	5	160	30 April 2016
4	SD Inpres Daya	Biringkanaya	6	239	3 May 2016
5	SD Inpres Hartaco Indah	Tamalate	5	126	7 May 2016
6	SD Unggulan Toddopuli	Panakkukang	6	224	12 May 2016
Total			33	1.111	

3.2. Microclimate conditions

In general, micro-climatic conditions in the classrooms at the time of measurement in 33 classes from six elementary schools can be seen in Table 2, which shows the minimum air temperature in the morning (08:00) 28.33^{o}C and the maximum during the daytime (14:20) of 34.29^{o}C. The temperature shows that classrooms in the surveyed primary schools experiencing excessive heat. The air temperature is outside the comfort zone as specified in the national standard (BSN, 2011). Air humidity is ranging from 53% - 89% with an average of 68%, indicating that the air humidity is within the comfort zone. Most of the classes have the average airflow rate is low, which is less than 0.5 m/s.

Table 2: Microclimatic conditions recorded at the surveyed classrooms

Schools name	Time of Measurements	Statistic	Air Temp (^{O}C)	RH (%)	MRT (^{O}C)	Air Velocity (m/s)
SD Inpres Nipa-Nipa	08.00-14.00	Average	30.87	66.50	30.86	0.13
		Min	28.33	54.55	28.78	0.00
		Max	33.18	75.90	32.85	1.29
SD Negeri Sudirman 1	08.00-11.00	Average	30.00	71.35	29.72	0.10
		Min	29.32	63.69	29.24	0.00
		Max	30.78	77.50	30.32	0.53
SD Inpres Tamalanrea 4	08.00-10.50	Average	30.91	70.48	30.65	0.06
		Min	28.87	58.86	29.02	0.00
		Max	32.90	78.30	32.39	1.25
SD Inpres Daya	09.05-14.20	Average	32.12	67.97	32.06	0.13
		Min	29.17	56.10	30.34	0.00
		Max	34.29	88.79	35.26	1.45
SD Inpres Hartaco Indah	09.20-12.15	Average	32.59	64.11	32.52	0.08
		Min	31.28	53.64	31.07	0.00
		Max	33.57	78.97	33.31	1.44
SD Unggulan Toddopuli	07.55-11.35	Average	32.10	67.73	31.99	0.10
		Min	29.44	56.04	29.88	0.00
		Max	33.97	77.65	33.79	1.09
Total		Average	31.43	68.02	31.30	0.10
		Min	28.33	53.64	28.78	0.00
		Max	34.29	88.79	35.26	1.45

3.3. Students' responses to the air temperature

Figure 3 illustrates the students' responses to the air temperature in the classrooms based on indicators of Thermal Sensation Vote (TSV), Thermal Comfort Vote (TCV), and also the Predicted Mean Vote (PMV). Based on the TSV, about 43% of respondents voted the hot regions (+1 to +3) and only 29% voted the cold region (-1 up to -3). The percentage of respondents who felt 'neutral' is less than 30%. These indicate that most of the students in the surveyed classrooms felt hot (uncomfortable).

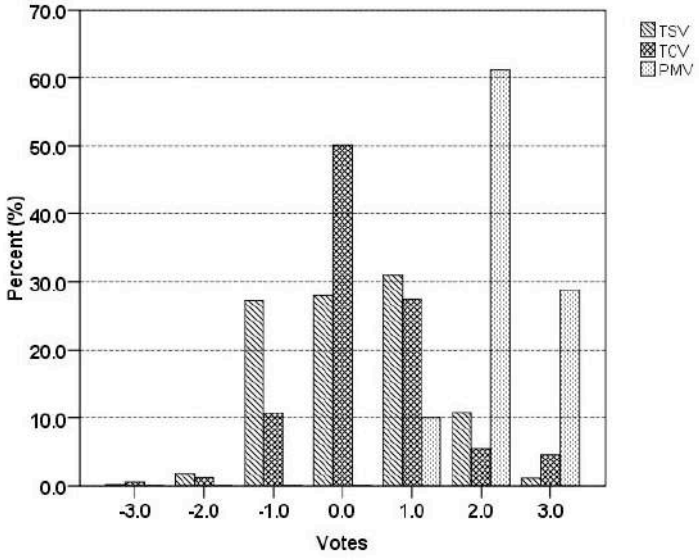

Figure 3: Thermal Sensation Votes (TSV) and Thermal Comfort Votes (TCV) of students

More than 38% of respondents voted the hot regions (+1 to +3) and only 12% in the cold region (-1 to -3) in the Bedford scale (TCV). Interestingly, about 50% of respondents felt comfortable in the classrooms. This figure quite different with the ASHRAE level (TSV) was less than 30% of respondents voted neutral. These suggest that both of these indicators, despite using the same size but gave a different result. It looks more respondents understand the word 'comfortable' than 'neutral'.

Very different figure have resulted from the calculated of PMV. In the PMV model, all respondents were predicted to have voted in the hot region (1 to 3). This figure indicates that the PMV model overestimated the actual votes of those surveyed. According to this PMV model, no students will feel 'neutral' or 'comfortable' in these surveyed classrooms. The results gathered using PMV method were very different with the actual votes either by TSV or TCV, where about 28% and 50% respondents felt 'neutral' and 'comfortable', respectively. This indication might not be appropriate to use PMV to estimate the thermal comfort of respondents in naturally ventilated rooms in the tropic. Feriadi and Wong (2004), and Wong and Khoo (2003) have suggested similar results.

Figure 4 presents students' response to the air temperature in the classrooms based on indicators of Thermal Preference and Thermal Acceptance. The left part of the figure shows that the majority of respondents (72%) want to decrease the air temperature in the classrooms and only very few (0.7%) of those want to increase the air temperature. Less than a third of respondents (27%) feel the temperature

is right so do not want to increase or decrease the air temperature. These responses imply that most of the students feel that the air temperatures were not within their thermal preferences.

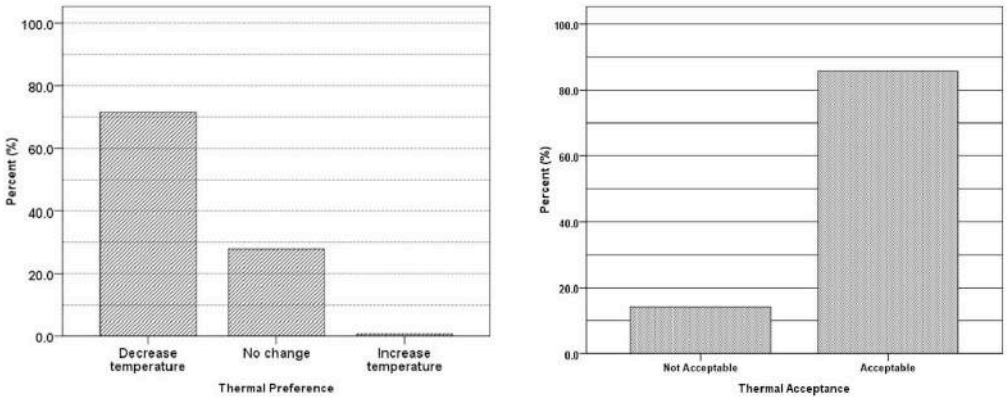

Figure 4: Thermal preference (left) and thermal acceptance (right) of students

As seen in right part of Figure 4 the majority of respondents (86%) accepted the thermal conditions of the classrooms and only a small proportion of them (14%) did not accept thermal conditions of the classrooms. These may indicate that students, even though more than 40% respondents felt hot (+1 to +3) they still can accept the condition of classrooms for learning process.

3.4. Students' response to air velocity

Students' response to the airflow in classrooms based on indicators Air velocity votes and the Air velocity preference can be seen in Figure 5. The figure shows that the majority of respondents (70%) had no or only very few feel the airflow in classrooms and only about 28 % who felt the presence of sufficient air flow, as well as about 2%, feel disturbed by the movement of air in classrooms. These may indicate that the existing ventilation system was not able to supply enough airflow into the classrooms.

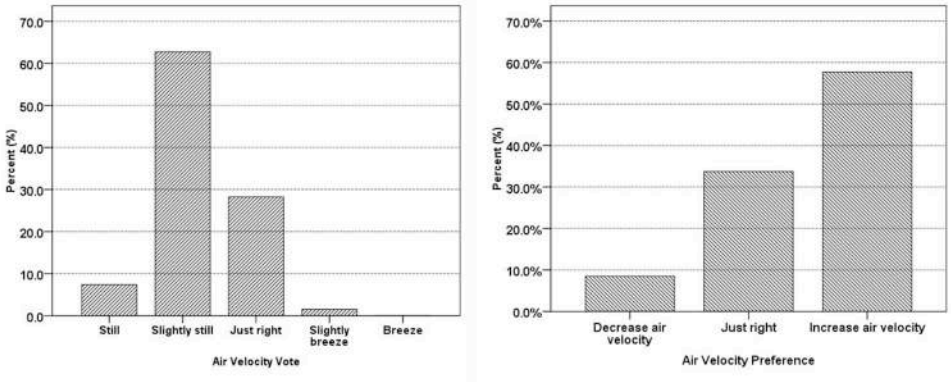

Figure 5: Students' response on air velocity

Regarding Air velocity preference, the majority of respondents (58%) preferred to increase the air velocity in the classrooms, and only about 8% wanted a decrease in the speed of air. When compared

with the choice of the condition of the air velocity, there is a difference, where only about 2% who feel disturbed by airflow there, but there were about 8% who want the reduction in air velocity. There is also a difference between choosing airflow 'enough' (just right) that as much as 28% compared with those not wanting an increase or decrease in airflow (34%).

3.5 Students' response to air humidity

Students' response to humidity conditions in the classroom based on the indicators Humidity votes can be seen in Figure 6. It is regarded that more than a third of respondents (37%) feel the humidity enough (just right), almost the same as choosing indoor air moisture (39%). The respondents' votes of the humidity in the classrooms were mostly influenced by the humidity of classes as seen in Table 2.

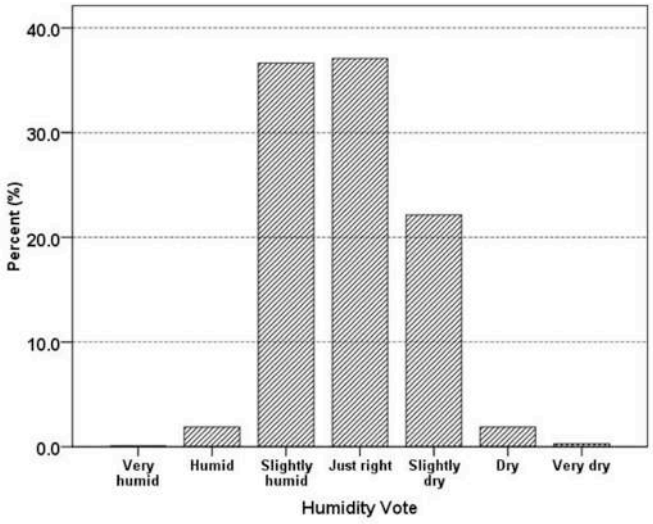

Figure 6: Students' response to the air humidity

As shown in Table 2, the humidity of classrooms was minimum 54%, average 68% and maximum 88%. These mostly lay in a comfortable zone as mentioned in the national standard (SNI Standard No. 6390:2011) (BSN, 2011). These values indicate that most of the classes were humid and no classrooms were dry. In contrast, about 24% of respondents voted that the classrooms were drained. This figure indicates that students of elementary schools were hard to determine the humidity of classrooms.

3.6. Neutral Temperature (T_n)

Figure 7 demonstrates the relationship between the operative temperature (Top) with a value of PMV, TSV and TCV. The following part describes the relationship between these three couples in producing neutral temperature values. Regarding PMV, Figure 7 shows most of PMV values lay in the hot regions (+1 to +3). With operative temperature is ranging from 28,5oC to 34oC the regression equation (R2 0.91) gives the relationship equation as follows:

$$PMV = 0{,}37T_{op} - 9{,}37 \quad (1)$$

By using equation (1), then the value of PMV = 0 (T_n) obtained when the operating temperature 25,50°C. This value means that the respondents would feel neutral (neither hot nor too cold) at 25,50°C (T_{op}). This value must be minimal if compared with an average temperature of classrooms ranging from 28,5°C up to 34°C. So if we use this PMV formula to predict the thermal comfort of the respondent, then there will be no respondents who feel neutral (comfortable).

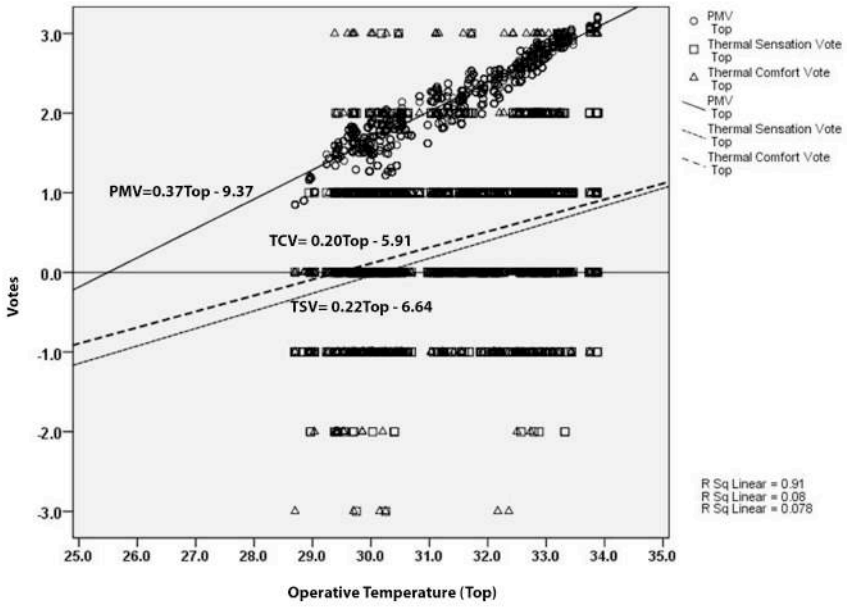

Figure 7: Regression between the operative temperature (T_{op}) with PMV, TSV, and TCV

The very different number is found in the relation between T_{op} and TSV. With the R^2 0.08 the linear regression analysis between T_{op} and the TSV is shown in the following equation relationship:

$$TSV = 0{,}22T_{op} - 6{,}64 \quad (2)$$

The T_n obtained from this equation is 30,20°C, which means that the respondents would feel neutral at a temperature of 30,20°C (T_{op}). This temperature value is higher than the temperature of the neutral using the PMV.

There is a similarity of the relationship between the T_{op} and TCV and the T_{op} and TSV. With R^2 0.08 gives the relationship equation as follows:

$$TCV = 0{,}20T_{op} - 5{,}91 \quad (3)$$

The T_n obtained from this equation is 29,40°C, which means that the respondents would feel neutral at a temperature of 29,40°C (T_{op}). This temperature value is higher than the temperature of the neutral using the PMV and slightly lower than the neutral temperature using TSV.

4. Conclusion

The condition of classrooms in selected primary schools in Makassar showed hot situation. It is characterised by high temperatures, high relative humidity and very low air velocity during the daytime.

The thermal comfort survey results show that the elementary school students are quite tolerant to high temperatures. Even though only a small percentage of respondents (28%) feel neutral in comparison with respondents who feel warm and hot (43%), 86% of them accepted these conditions. However, more than 72% of respondents preferred to decrease the air temperature in the classrooms. Most respondents did not feel the airflow in the classrooms so that most of them want the increase in airflow velocity. The result of the calculation of neutral temperature (T_n) using a model Predicted mean vote (PMV) produces the value 25.5°C which is very low when compared with the air temperature in the room. This result is less than the value of the neutral temperature (Tn) obtained from the questionnaire either by using Thermal sensation vote (TSV) for 30,2^{o}C or Thermal comfort vote (TCV) of 29,4^{o}C.

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